

Innovation Focus Areas for Compressed Hydrogen and Natural Gas Storage

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Manufacturing Automation and Recycling for Clean Hydrogen Technologies Experts Meeting

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Hexagon Background

- Hexagon is a leading global provider of clean fuel solutions, including hydrogen, compressed natural gas (CNG), liquefied petroleum gas (LPG), and electric.
- Hexagon R&D (Lincoln, NE) – Focus on composite and pressure vessel innovation.
 - Lincoln background – Began with defense and aerospace products, have successfully moved to commercial and automotive (600,000+ cylinders sold since transition to commercial products)

Hexagon Agility Clean Solutions



Medium and
Heavy-Duty Vehicles

Hexagon Purus



Hydrogen
applications, CNG
Light-Duty Vehicles,
and battery electric
drivetrain

Hexagon Agility Mobile Pipeline



Gas Transportation

Hexagon Ragasco



LPG Cylinders

Hexagon Digital Wave



Cylinder health
monitoring and smart
systems



Leading product competence

Global leader in type 4 pressure vessel technology



Trusted customer relationships

Established successful collaborations with major OEMs and leading fleet operators



Established operational footprint

Engineering centers and serial production facilities in North America and EU

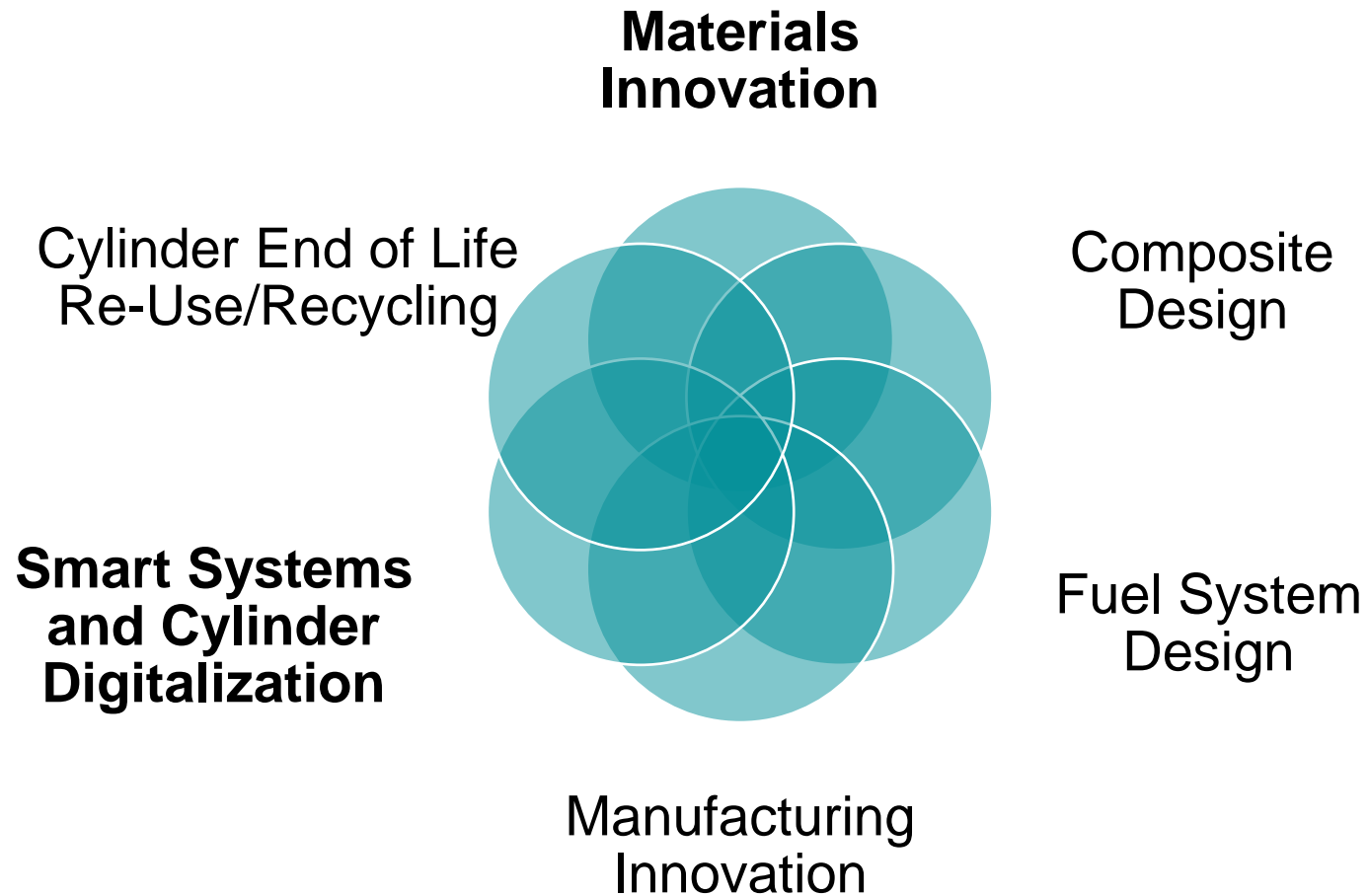


Extensive industry track record

Decades of experience in pressure vessels and clean fuel systems



Hexagon Group Innovation Focus Areas



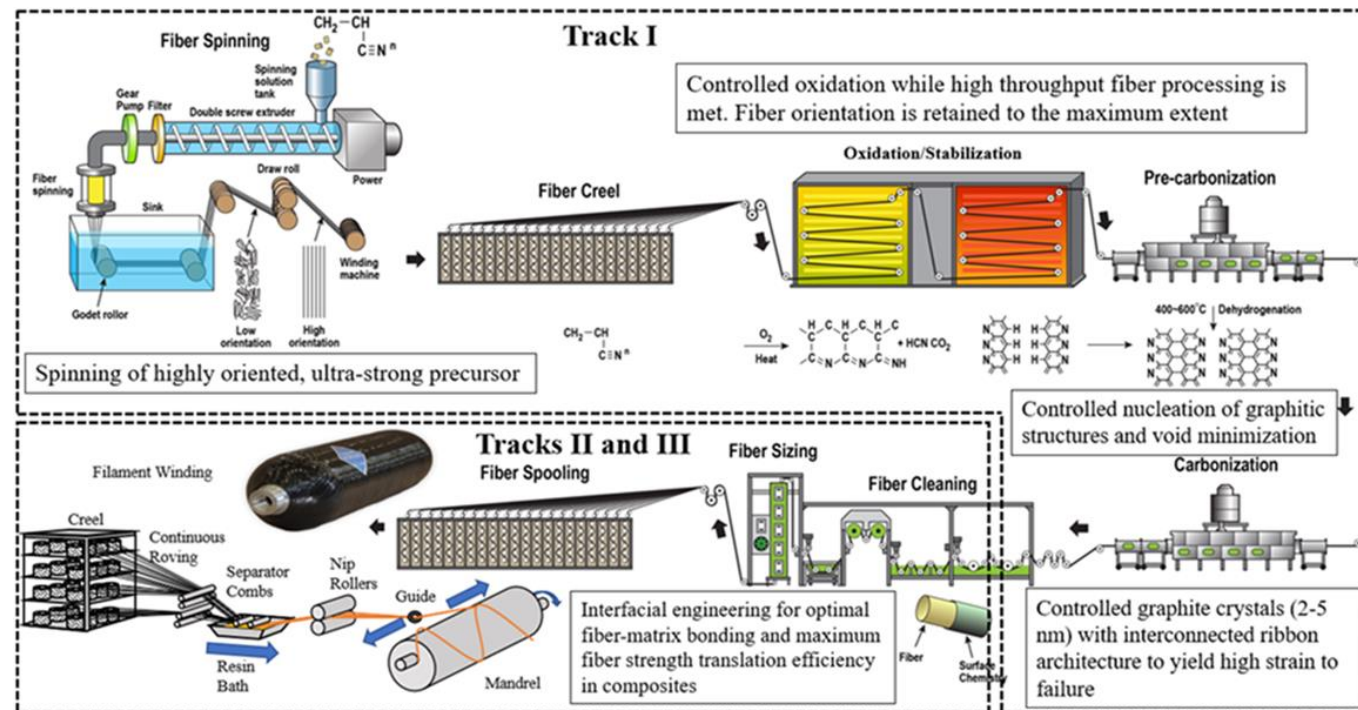
Presentation topics

- Materials innovation – carbon fiber
- Smart systems and cylinder digitalization

Carbon Fiber Materials Innovation – Current DOE Activity

H2@Scale Advanced Carbon Fiber For Compressed Hydrogen and CNG Storage Tanks

- Prime award – Carbon Composite Optimization Reducing Tank Cost (CORTC)
- Subawards
 - Low-Cost, High-Performance Carbon Fiber (Prime – University of Virginia)
 - Melt Spun Polyacrylonitrile Precursor (Prime – Collaborative Composite Solutions)

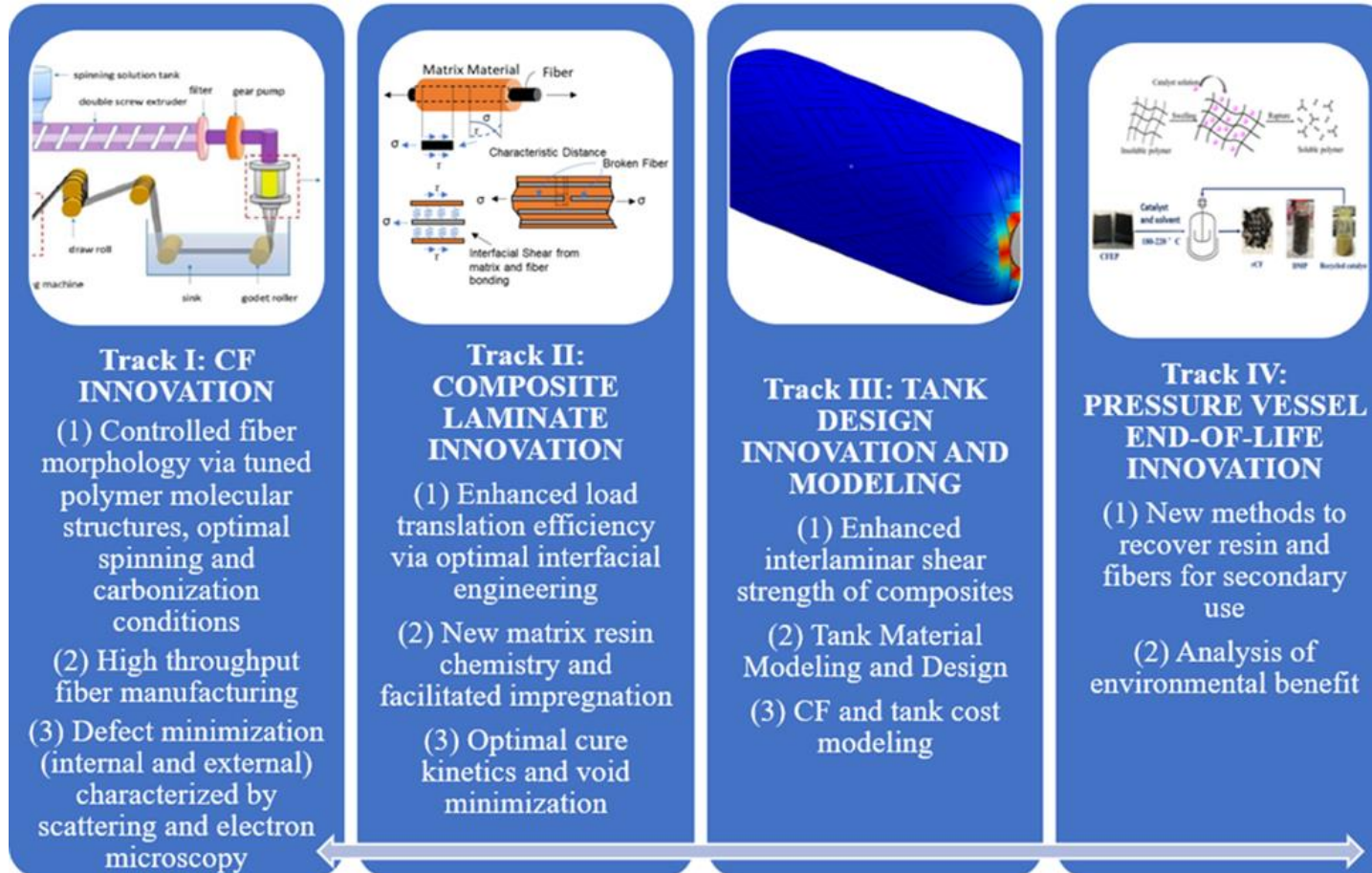


Carbon Fiber Materials Innovation – Relevance

- Gas storage tank cost is a significant barrier to the mass deployment of cleaner vehicle fuel sources such as hydrogen and CNG.
- Carbon fiber (CF) accounts for approximately 50% of the total hydrogen storage system cost.
- The overall project objective is to reduce hydrogen and CNG storage system costs with newly developed technologies to produce low-cost, high strength CF to accelerate mass deployment of hydrogen and/or CNG fueled vehicles.
 - CF cost target < \$15/kg, capable of 700 ksi tensile strength (TS) and 35 Msi tensile modulus (TM)
 - Additional project goals
 - Demonstrate >25% tank system cost reduction
 - Long-term stretch goal of further CF cost reduction
- Project and overall DOE targets

	Baseline	Project Target	Ultimate Target
Benchmark CF cost (Toray T700S)	\$26-30/kg	\$13-15/kg	
250 bar pressure vessel		10% cost reduction	
Total system cost	\$16/kWh		\$8/kWh






CORTC Team and Approach – Four Tracks of Innovation



Further funding will be crucial in overcoming significant investment barriers to accelerating the deployment of commercial production of the newly developed technologies for low-cost, high-strength carbon fiber.



Digitizing Cylinder Systems – Benefits

Benefit for customers	Description
 Safety improvement	Live health monitoring of the cylinder system identifies damages to the system
 Second life enablement	Continuous data gathering and analysis of the cylinder system creates opportunities for usage beyond the initial lifetime
 TCO reduction	Reduced downtime through a minimum of 2x lifetime extension and improved residual value, efficient and predictive maintenance, more efficient cylinder designs and reduced insurance and warranty costs
 Reduced risk of ownership	Leasing based business models shifts the risk of ownership away from the customer when deciding to invest in a new technology. In addition, enablement of secondhand markets reduces the risk of ownership further
 Sustainability improvement	Through second life enablement and more efficient cylinder designs, less resources will be used in a circular economy

“ ”

“Having the possibility of **full surveillance of the cylinder** is a **key factor** in choosing the cylinder”

Truck fleet manager

“A **turnkey solution** and direct replacement of their diesel product with lower TCO, ESG targets and without needing to build the expertise inhouse would be a home-run”

- OEM

“Leasing would be interesting if it decreased costs, and the **end of life handling was taken care of**”

- Large truck fleet manager

“With live-monitoring, our **technicians could quickly identify problems** and decide if they need to pull in the truck”

- Large truck fleet manager



Digitizing Cylinder Systems – Improved safety, reduced cost, improvement of the circular economy with extended cylinder life

Smart sensors 1

Enables digital use cases (temperature, pressure, GPS and acoustic)



Tailored filling 2

Real sensor data instead of algorithms enable full use and fill of cylinders



Live health monitoring 3

Real time notifications on status of cylinder & if it's safe to drive and/or refill



Predictive maintenance 4

Reduced customer downtime with increased knowledge of when service is needed



Extended life 5

Increased knowledge of the underlying asset enables re-use of existing cylinders



Improved designs 6

Usage data will allow more efficient cylinder designs and reduce cost per unit



Wrap-Up

Key Opportunities for Future Development Funding and Innovation

- Automation of carbon fiber manufacturing
- Optimization of fiber/resin laminate design
- Cylinder manufacturing process innovation
- Smart systems and cylinder digitalization
- Re-fueling station infrastructure in low population density areas – new hydrogen corridors
- Cylinder end of life extension and repurposing
- Cylinder end of life recycling



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